RESEARCH DEPARTMENT

INTERIM REPORT ON THE LONG DISTANCE PROPAGATION OF A VERY

HIGH FREQUENCY (94·35 Mc/s) OVER THE NORTH SEA

1st JULY 1954-31st JULY 1955

Report No. K-107

(1956/5)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

The experiment described in this report was conducted jointly by the Netherlands Postal and Telecommunications Services and the British Broadcasting Corporation as a contribution to the knowledge of v.h.f. propagation over sea paths. Transmissions on 94·35 Mc/s were made from Holland over the North Sea, and reception of these was obtained at five sites along the British North Sea coast.

Curves have been plotted:

a. For all receiving sites: showing the percentage valid recording time during which the field strength exceeded given values for the periods 0900–2300 hours, 0900–1800 hours and 1800–2300 hours GMT.

b. Showing the comparison between the results of this experiment and the C.C.I.R. curves attached to Recommendation No. 111 (London 1953).

1. INTRODUCTION.

A large number of experiments on v.h.f. tropospheric propagation over land has been carried out by various countries, but comparatively little work has been done upon the matter of such propagation over sea paths.

In order to obtain data on this subject, and as part of the C.C.I.R. Study Programme No. 55(2), the British Broadcasting Corporation, with the aid and co-operation of the Netherlands Postal and Telecommunications Services, carried out an experiment over the North Sea for some thirteen months. The details of this experiment, together with its preliminary results, form the subject of this interim report.

Transmitting equipment, suitable for operating on a frequency of 94·35 Mc/s, was installed at Scheveningen in Holland, on an existing site. The receiving sites were on the East Coast of Great Britain at the following locations:

Happisburgh, Norfolk
Flamborough Head, Yorkshire
Newton-by-the-Sea, Northumberland
Bridge of Don, Aberdeenshire
Lerwick, Shetland Islands.

The considerations governing the choice of these sites were their proximity to the sea and their freedom from local interference.

Records of field strength were made from 1st July 1954 to 30th September 1955, from 0900—2300 hours daily. This fourteen—hour period was chosen as representing the normal hours of television and v.h.f. sound broadcasting.

This report, however, deals only with the period 1st July 1954 to 31st July 1955 because the analysis of the results is complete only until the latter date. The results for the period 1st August to 30th September 1955 will be available later.

2. TRANSMITTER.

Scheveningen, the site chosen for the transmitter, is 9 metres above sea level and is situated in latitude 52° 06' N, longitude 04° 16' E.

The output power of the transmitter was 600 W (—2·2 dB with reference to 1 kW). Its frequency was maintained by a stable LC oscillator, which in turn was controlled by an AFC system governed by a crystal oscillator. The carrier was unmodulated, but for a period of six seconds every two minutes the frequency was reduced by 75 kc/s for the purpose of identification.

The transmitting aerial was a six—element Yagi array mounted horizontally at a height of 164 ft (50 m) above ground level. The aerial was oriented with its maximum radiation at 320° E of true north, thus directing the higher effective radiated power towards the more remote sites. The gain along the axis was 9·3 dB over a half—wave dipole, making the effective radiated power in this direction +4·3 dB with reference to 1 kW, using a feeder whose loss was 2·8 dB.

Of the total of 396 days occupied by the period mentioned above, valid records were obtained on 366 days.

3. RECEIVERS.

Stable crystal—controlled double superheterodyne receivers were installed at the sites, and after detection subsequent to the second intermediate frequency stage the output was fed to a recording milliammeter. The chart speeds were three inches (7·6 cm) per hour.

The receivers had a bandwidth of ± 40 kc/s at the 3 dB points, wide enough to allow for slight drift of the transmitter frequency. During the identification periods when the transmitter frequency was reduced by 75 kc/s, a drop of approximately 24 dB in receiver output level resulted.

Three—element Yagi receiving aerials were mounted horizontally at a height of 30 ft (9·2 m) above ground level and were directed towards the transmitter. These aerials had a gain of 6 dB relative to a half—wave dipole.

4. CALIBRATION.

The gain of the receivers was monitored at intervals by a local calibration oscillator whose output was maintained constant by a thermistor circuit. For a

period of two minutes every one-and-a-half hours the aerial of each receiver was automatically disconnected and the output of the calibration oscillator switched to the input of the receiver. In this way a check on the calibration of the receiver was made.

Routine tests on the receiving aerials ensured that the characteristics remained constant during the period of the experiment.

5. SITES.

Fig. 1 gives the geographical position of the B.B.C. receiving stations. In all cases the sites were within 3000 ft (914·5 m) of the sea, and in no instance was there any obstruction from the aerial to the horizon in the direction of the transmitter.

Table 1 gives the relevant data.

TABLE 1

Site	Distance from Scheveningen		Site Height above sea level		Bearing of Site from Scheveningen (true)	Latitude	Longitude
	Miles	km	ft	m			
Happisburgh	123	198	50	15·2	295°	52° 49' 42" N	01° 31' 38" E
Flamborough Head	227	365	150	45·7	309°	54° 07' 39" N	00° 05' 40" W
Newton-by-the-Sea	338	543	70	21·3	317°	55° 31' 06" N	01° 37' 05" W
Bridge of Don	429	690	30	9·2	326°	57° 10' 40" N	02° 05' 00" W
Lerwick	591	950	300	91·5	342°	60° 08' 00" N	01° 10' 20" W

6. GENERAL.

The field strength values quoted in this report are given in decibels relative to one microvolt per metre, normalised for an effective radiated power of 1 kW.

Widely different weather conditions were experienced during the experiment. The summer of 1954 was dominated by frequent and active depressions, and was followed by a mainly cyclonic winter. During the summer of 1955, however, anticyclonic weather was more in evidence and the whole period thus included all the conditions normally experienced in these latitudes. It is felt, therefore, that the period may be considered as fairly representative of average weather conditions.

At Bridge of Don and Lerwick, the two most distant sites, no signals were received until January and April 1955 respectively. At both these sites strong signals were received between April and July 1955, as they were also at the nearer sites.
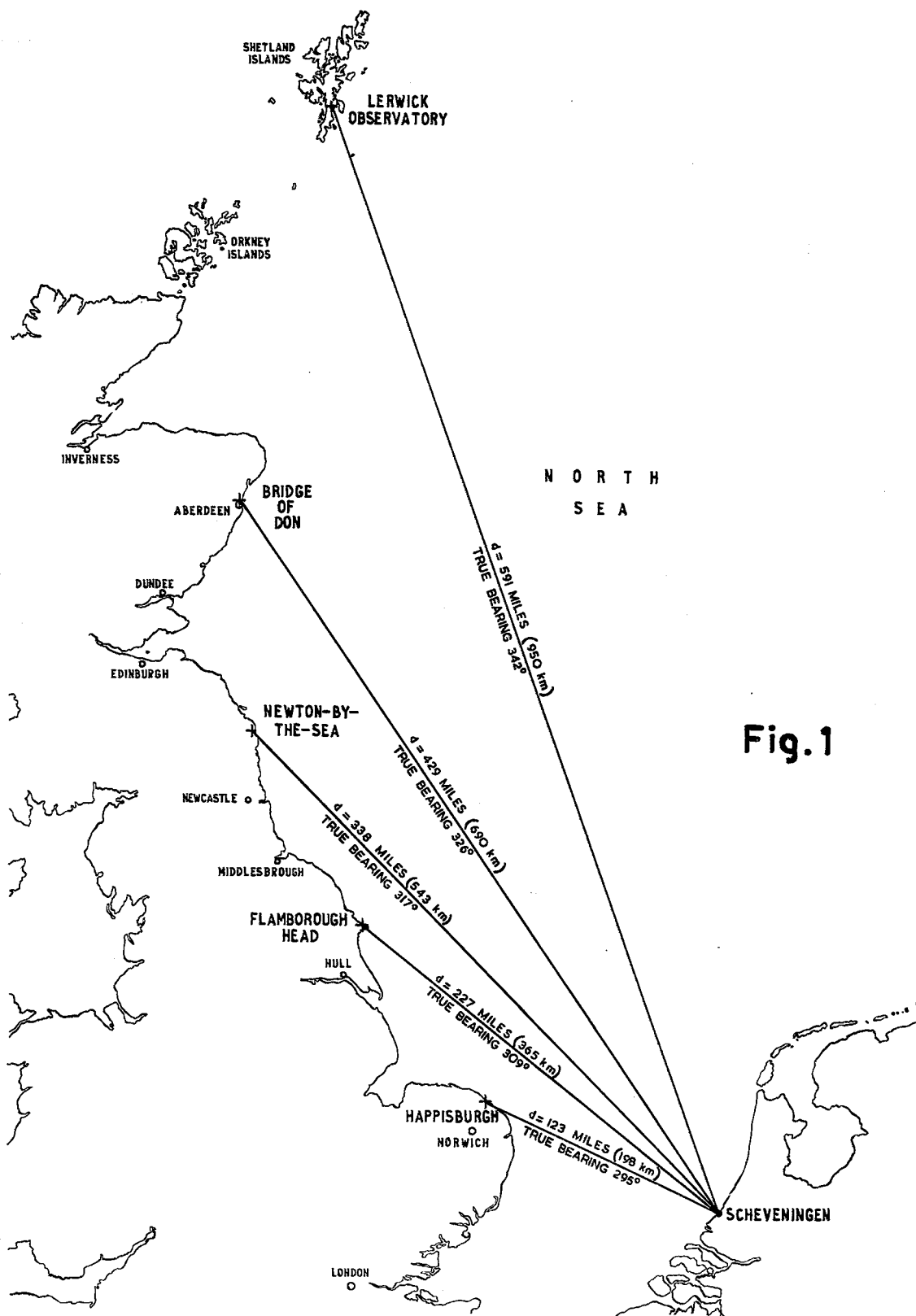
Fig.1

At the **receiving sites** some recording days were lost, mainly owing to initial difficulties with the stabilised power supplies for the receivers. With the exception of Lerwick, the sites were not continuously attended by technical personnel and therefore, when a fault occurred, delay was inevitable before an engineer could reach the site.

It was not possible to choose receiving sites which were similar to each other in regard to altitude, distance from the sea and local terrain. These factors may therefore have influenced the results. It is proposed, however, at a later date, to conduct a few experiments in the neighbourhood of Happisburgh and Flamborough Head with an additional receiver to investigate possible local effects due to site altitude, etc. Owing to the small percentage of time that any signals are received it is impracticable to do such location tests at the more distant sites.

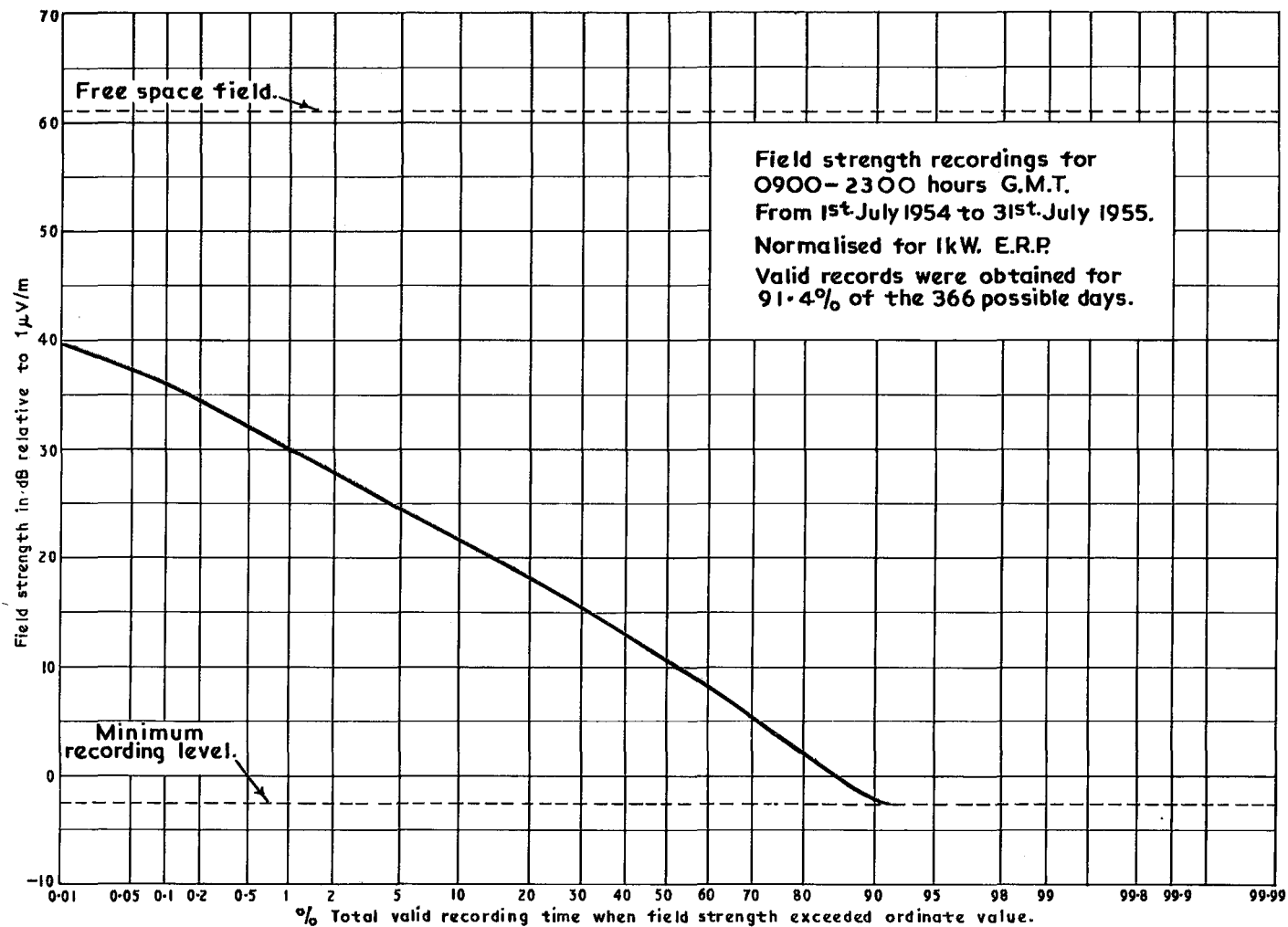## 7. INTERPRETATION OF RESULTS.

7.1. Results: General.

The curves show the percentage valid recording time during which the field strength exceeded given values for the periods 0900–1800 hours, 1800–2300 hours and 0900–2300 hours GMT.

At Newton–by–the–Sea, Bridge of Don and Lerwick (Fig. 4) the highest percentage values plotted are 3·2%, 1·05% and 0·72% respectively, and thus at these longer distances the signal, above minimum recording level, is never present for a proportion approaching 10% of the total valid recording time.
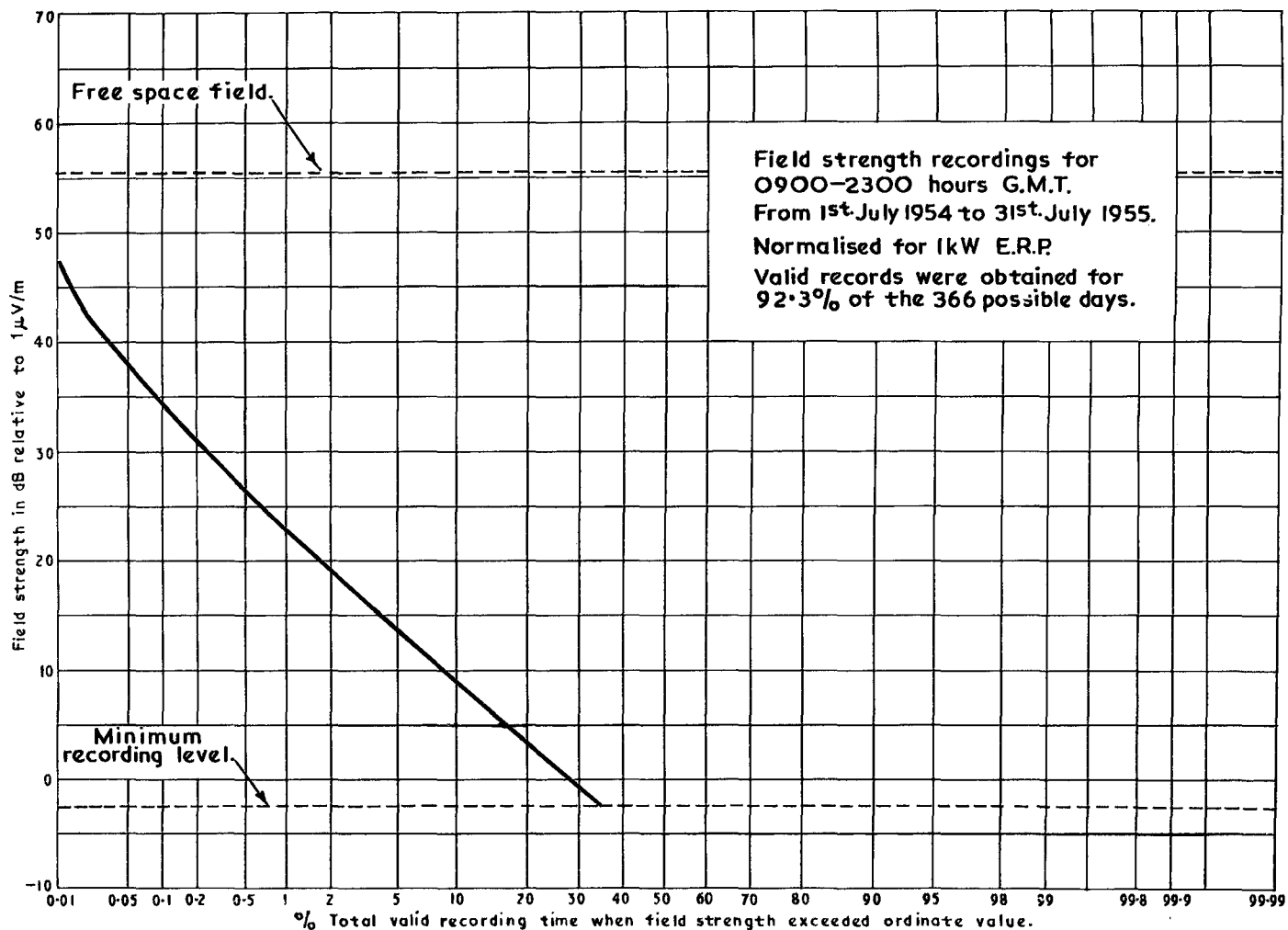
Fig. 5 shows that, at the nearer receiving site, the field strength was, at 0·1% of the total valid recording time, 2·3 dB greater for the period 1800–2300 hours than for that at 0900–1800 hours. At the 1% value it is 1·6 dB greater and at the 10% value 0·9 dB greater. These small differences between the field strengths for the two periods may not be important, but for the other sites (Figs. 6 and 7) the increase of the 1800–2300 hours field strength over that for the 0900–1800 hours period becomes more pronounced. Details are given in Table 2:

TABLE 2

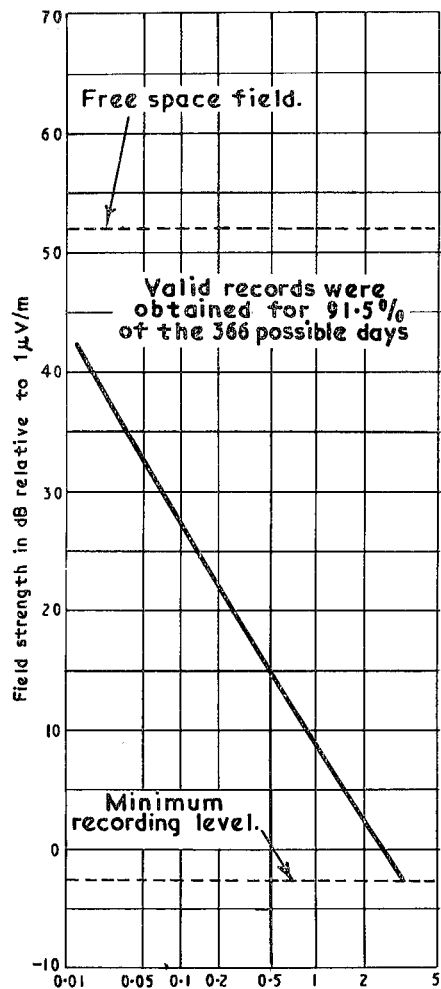| Site	dB increase in field strength for certain percentages of recording time for evening as compared with daytime periods (Figs. 5–7)		
	0·1%	1%	10%
Happisburgh	2·3	1·6	0·9
Flamborough Head	6·5	2·6	1·1
Newton–by–the–Sea	14·0	3·0	—
Bridge of Don	19·0	—	—
Lerwick	15·0	—	—

Fig. 2 — Scheveningen 94·35 Mc/s C.W. transmissions received at
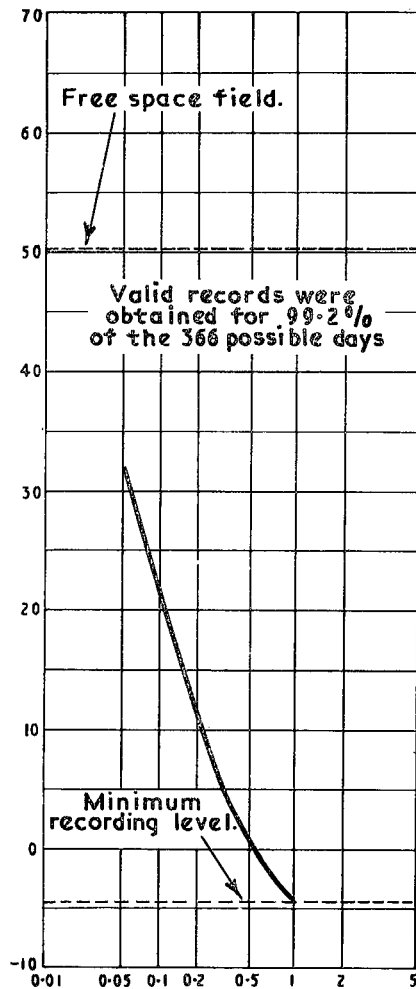HAPPISBURGH
(Distance 123 miles, 198 km)

Fig. 3 — Scheveningen 94·35 Mc/s C.W. transmissions received at
FLAMBOROUGH HEAD
(Distance 227 miles, 365 km)

NEWTON–BY–THE–SEA
(Distance 338 miles, 543 km)

BRIDGE OF DON
(Distance 429 miles, 690 km)

LERWICK
(Distance 591 miles, 950 km)

Free space field.

Valid records were obtained for 91·5% of the 366 possible days

Valid records were obtained for 99·2% of the 366 possible days

Valid records were obtained for 94·1% of the 366 possible days

Field strength in dB relative to 1μV/m

Minimum recording level.

% Total valid recording time when field strength exceeded ordinate value.

Fig. 4 — Scheveningen 94·35 Mc/s C.W. transmissions received at
NEWTON–BY–THE–SEA, BRIDGE OF DON AND LERWICK.

Field strength recordings for 0900–2300 hours G.M.T.   From 1st July 1954 to 31st July 1955.   Normalised for 1kW. E.R.P.

Fig.5 — Scheveningen 94·35 Mc/s C.W. transmissions received at
HAPPISBURGH
(Distance 123 miles, 198 km)

Fig. 6 — Scheveningen 94·35 Mc/s C.W. transmissions received at
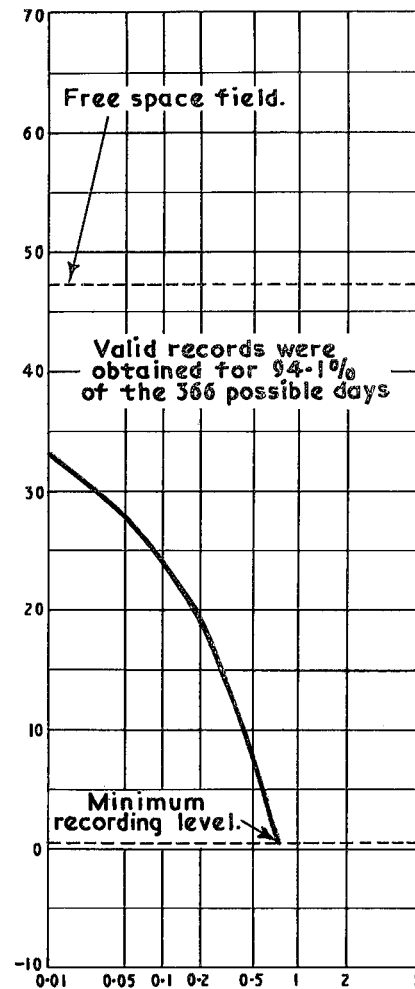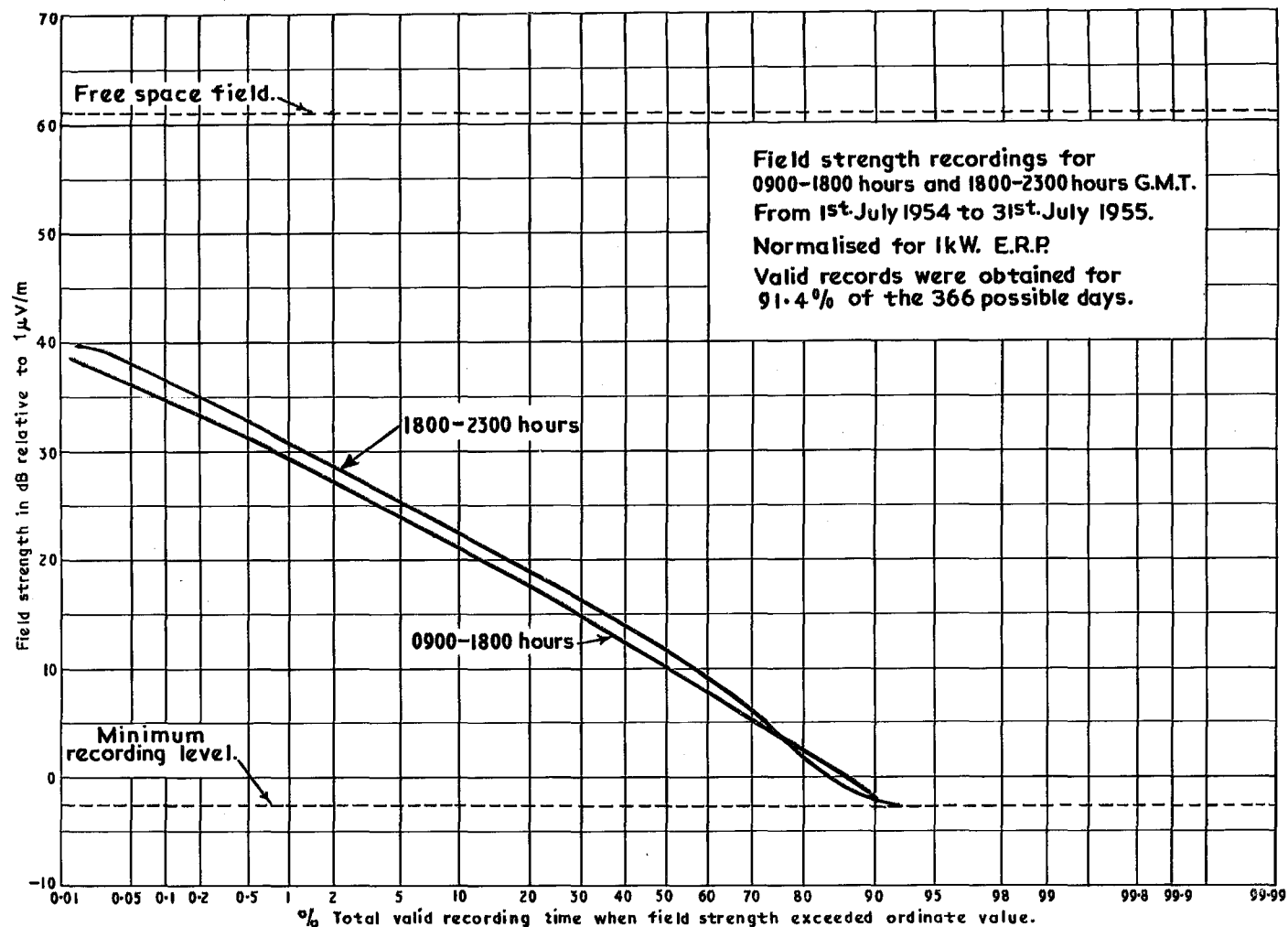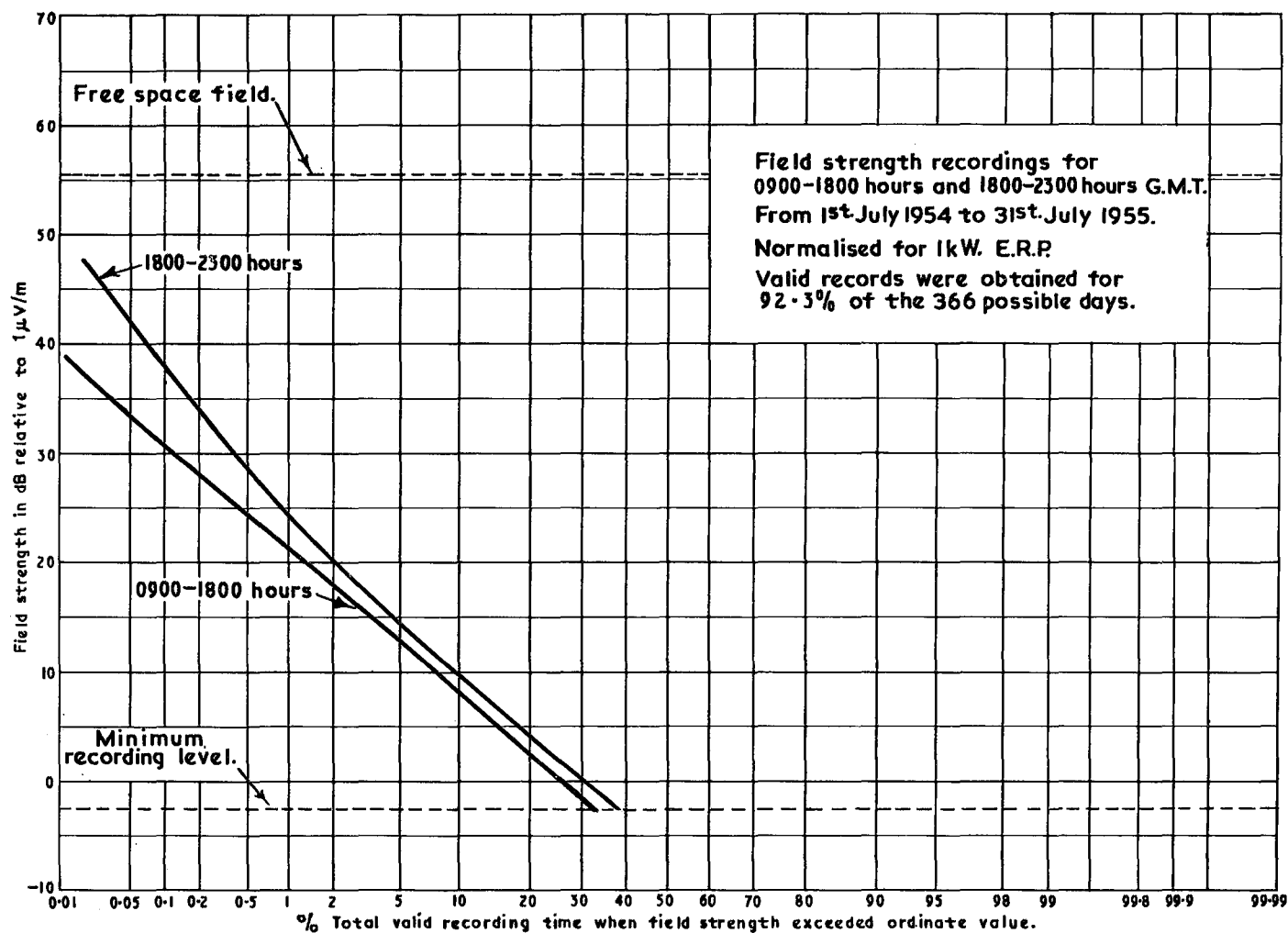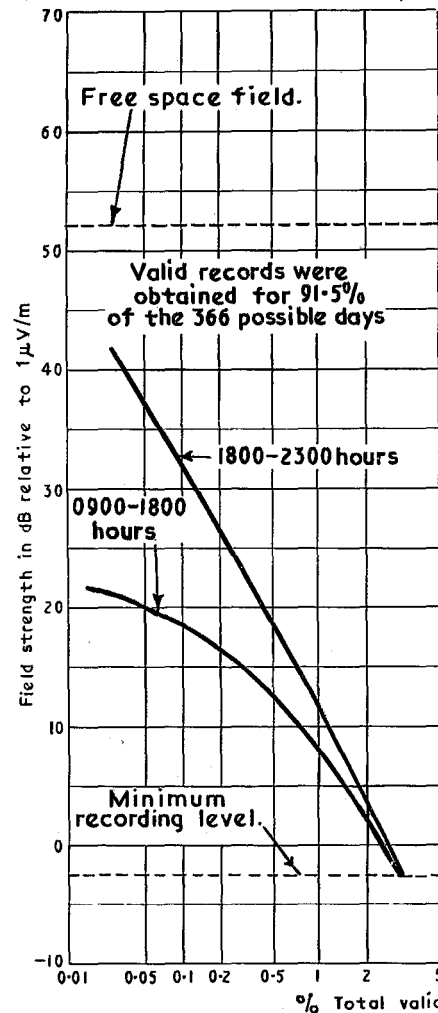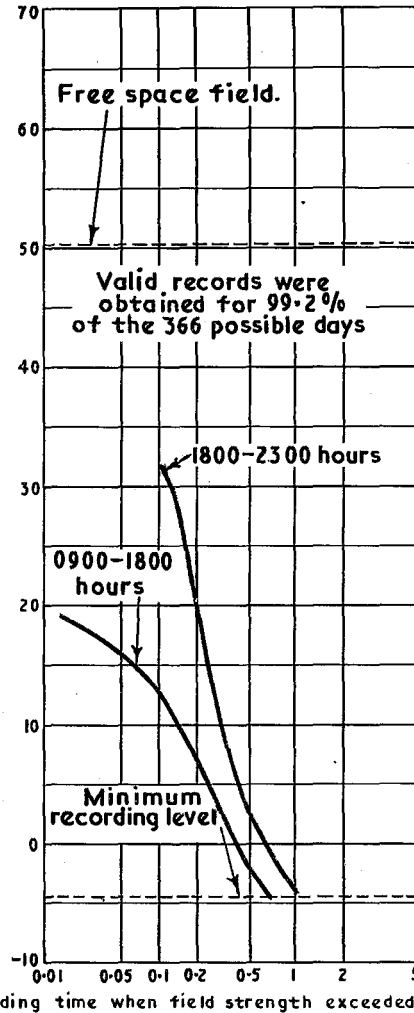FLAMBOROUGH HEAD
(Distance 227 miles, 365 km)

NEWTON-BY-THE-SEA (Distance 338 miles, 543 km)

BRIDGE OF DON (Distance 429 miles, 690 km)

LERWICK (Distance 591 miles, 950 km)

Free space field.

Valid records were obtained for 91·5% of the 366 possible days

1800-2300 hours

0900-1800 hours

Minimum recording level.

Valid records were obtained for 99·2% of the 366 possible days

1800-2300 hours

0900-1800 hours

Minimum recording level

Valid records were obtained for 94·1% of the 366 possible days.

1800-2300 hours

0900-1800 hours

Minimum recording level.

Field strength in dB relative to 1µV/m

% Total valid recording time when field strength exceeded ordinate value.
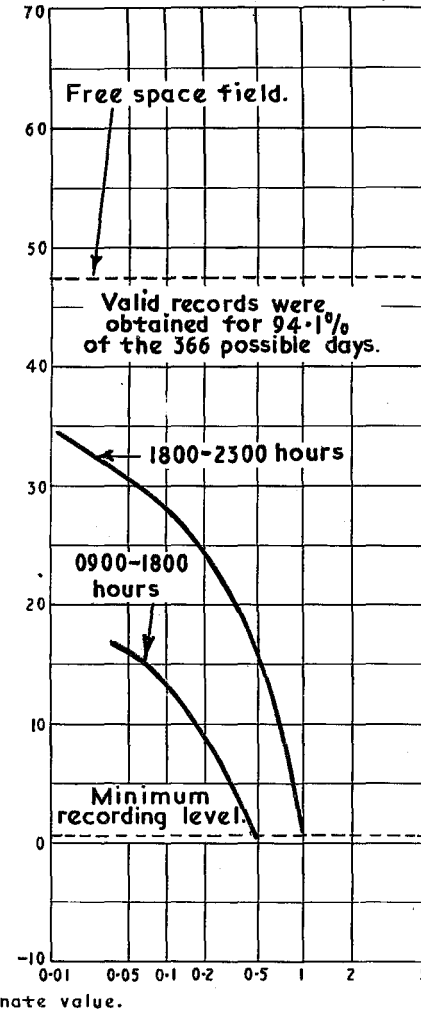
Fig. 7—Scheveningen 94·35 Mc/s C.W. transmissions received at
NEWTON-BY-THE-SEA. BRIDGE OF DON AND LERWICK.
Field strength recordings for 0900–1800 hours and 1800-2300 hours G.M.T.
From 1st July 1954 to 31st July 1955   Normalised for 1kW E.R.P.

The following points emerge from Table 2:

a. Propagation to the more distant sites improves in the evening. It should be mentioned, however, that although signals tend to be higher in the evening there is a greater depth of fading.

b. As shown in the column headed "0·1%" the difference between the 1800-2300 hours' curve and the 0900-1800 hours' curve increases with distance up to Bridge of Don. This appears to indicate that as the distance increases the superiority of the 1800-2300 hours field over that for 0900-1800 hours becomes greater until a peak is reached. A subsequent increase in distance results in a relative decrease, as is apparent in the case of Lerwick.

7.2. Peak Signals.

The daily peak signals were generally received between 1000-1200 hours and 1900-2300 hours GMT at Happisburgh and Flamborough Head, although they were not pronounced in comparison with the signals received throughout the day. The peak signals at Newton-by-the-Sea, Bridge of Don and Lerwick invariably occurred in the evening.

7.3. Abnormal Propagation.

When the air in the upper atmosphere is relatively warm and dry in comparison with the air at the surface, conditions are favourable for the occurrence of abnormal tropospheric propagation. Such meteorological conditions are most likely to occur when the anticyclonic type of weather prevails.

In this experiment high signals occurred mainly in April, May, June and July 1955, and were associated with high pressure areas over the North Sea and temperature inversions at 2000 to 5000 ft (609·6 to 1524 m) above sea level.

Table 3 gives the highest signals recorded at each receiving site.

TABLE 3

Site	Date	Free Space Field (dB ref. 1μV/m)	Maximum Field Strength Received (dB ref. 1μV/m)
Happisburgh	29th May 1955	61	44·6
Flamborough Head	29th May 1955	55·6	50·5
Newton-by-the-Sea	29th May 1955	52·2	47·2
Bridge of Don	25th July 1955	50·1	34·6
Lerwick	29th May 1955	47·3	35·7

All sites received a maximum signal on 29th May 1955 with the exception of Bridge of Don, where the signal was only 9·5 dB. On 25th July 1955, the date on which Bridge of Don received its maximum signal, the maximum signals at Happisburgh, Flamborough Head, Newton-by-the-Sea and Lerwick were 31·1 dB, 24·5 dB, 33·7 dB and 28·3 dB respectively.

There were days, one of them being 29th May 1955, when the field strengths at Flamborough Head and Newton-by-the-Sea were higher than those at Happisburgh.

These two sets of occurrences appear to indicate that the inversion layer responsible for abnormal tropospheric propagation may be of quite limited area, or else may not be of uniform structure throughout its extent, but it is, of course, impossible to assign an exact reason for them.

7.4. Types of Signal.

It is desirable to classify the various types of signals, and in general they may be grouped[1] as follows:

Type I   : Signals affected by comparatively little fading.
Type II : Signals affected by long term fading.
Type III : Signals affected by deep fading over short periods.

Types I and II are generally associated with anticyclonic weather conditions, whereas Type III is connected with cyclonic conditions.

All types of signals have been received at Happisburgh and Flamborough Head. When signals were received at the more distant sites of Newton-by-the-Sea, Bridge of Don and Lerwick, although present for only a small percentage of the total valid recording time, they were of Types I and II. It is significant that Type III signals were not recorded at the greater distances.

7.5. Comparison with C.C.I.R. Curves (London 1953)

Fig. 8 shows a plot of the field strength values exceeded at the various sites for 10%, 1% and 0·1% of the overall time of the experiment, in terms of distance from the transmitter. A curve has been drawn by an adaptation of least squares technique to obtain a parabolic approximation (see Appendix) for the 1% and 0·1% field strength values. The process of drawing a parabola through the rather widely scattered values may, in fact, have made some allowance for the local site variations referred to in section 6.

A 10% curve has not been drawn as there are insufficient points.

This figure also shows 10% and 1% curves from Recommendation No. 111 of the C.C.I.R.[2]

8. CONCLUSIONS.

The main purpose of this experiment was to investigate long distance v.h.f. propagation over sea paths and to compare the results obtained with an earlier investigation over land paths.

The results showed that for a given distance, the field strength over the sea is greater than that over the land. The field strength exceeded for 1% of the total time of the investigation showed an increase of about 3-9 dB within the distance range 100-400 km and about 9-11 dB within the range 400-700 km, when compared with the C.C.I.R. overland curves.

Fig. 8
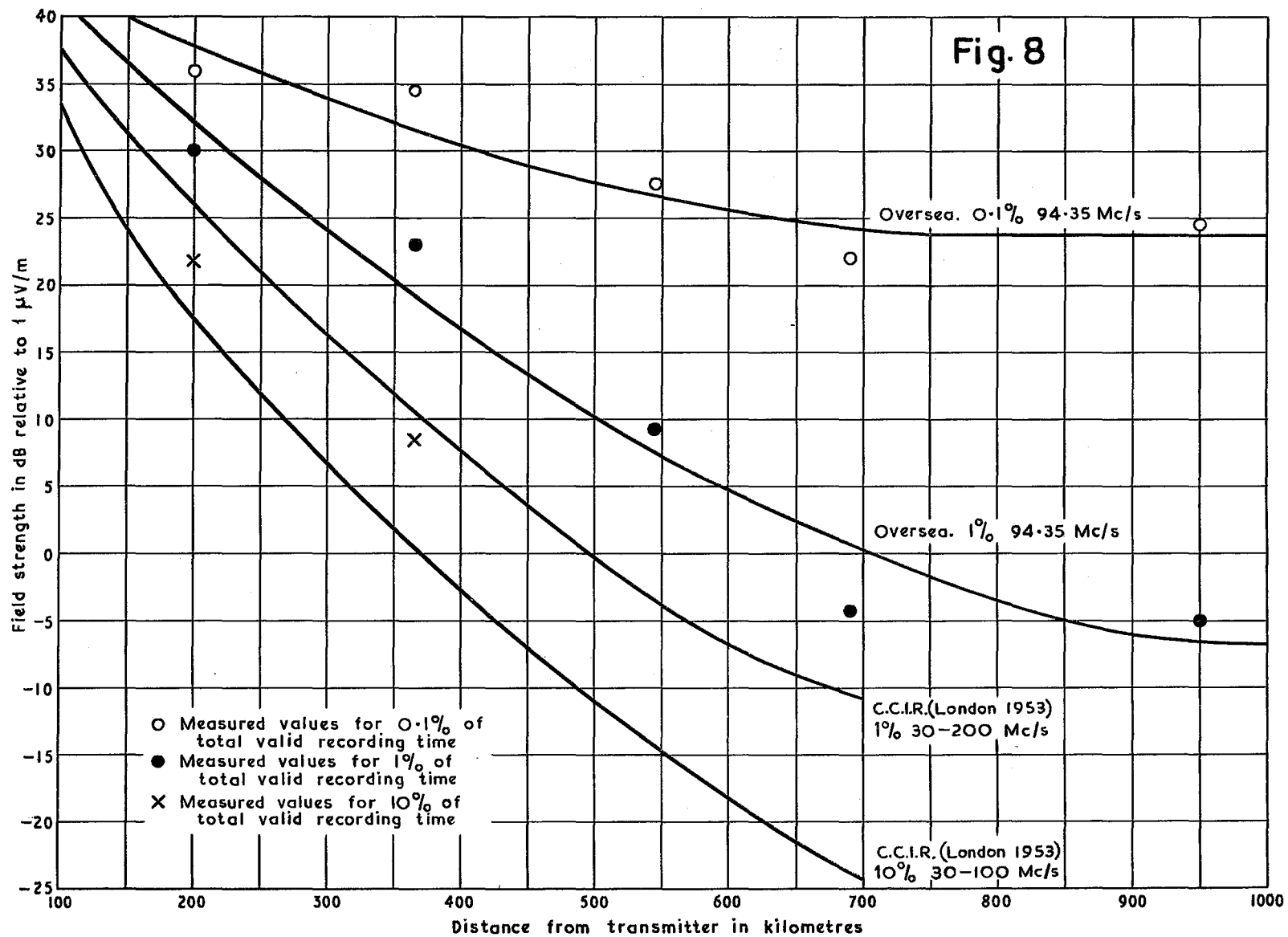
On the occasions when strong signals——such as are ascribed to abnormal tropospheric propagation——were received at the various sites it was invariably found that high pressure systems, coupled with temperature inversions, existed over the North Sea.

The further the distance from the transmitter the greater was the superiority of signals received during the evening period over those received during the daytime period.

There was a tendency for peak signals to be received during the periods 1000-1200 hours and 1900-2300 hours GMT.

When fading was experienced on the received signals it was, in the case of the nearer sites, sometimes of the deep fast and sometimes of the slow type, whereas signals received at the more distant sites exhibited only slow fading characteristics.

9. ACKNOWLEDGMENTS.

The B.B.C. acknowledges with grateful thanks the facilities provided by the Netherlands Postal and Telecommunications Services and, in particular, the staff of Scheveningen Radio Station who were responsible for installing and maintaining the transmitter.

Thanks are also due for the assistance and facilities given by the Senior Meteorological Officer and technical staff at Lerwick Observatory.   Acknowledgment is also made to the Ministry of Transport for permission to use its coastguard stations as receiving sites, and to the coastguard officers at these sites.

10. REFERENCES.

1. E.A. Lauter and L. Klinker, "The Influence of Weather Conditions on the Nature of Long Distance V.H.F. Reception".   Article from Zeitschrift für Meteorologie, Vol. 8, No. 7.8., July, August 1954.

2. Documents of the C.C.I.R. VIIth Plenary Assembly, London, 1953.   Vol. 1., page 140.

APPENDIX

An Empirical Technique for Obtaining Smooth Field Strength/Distance Curves
from a Limited Number of Observations

1. OBJECTIVE.

The problem here considered is how to derive, from a limited number of
observations of field strength as a function of distance at a given frequency, a
reasonable curve representing the variation of field strength due to distance alone.
The individual readings are taken at a few fixed sites, and factors other than
distance introduce a large scatter into the readings.   Our task is to try to
eliminate the effect of this scatter.

If the expected law of field strength (in decibels) against distance was
linear, we could determine the best-fitting straight line l by means of the technique
of least squares.   For this particular problem, however, we have reason to believe
that an empirical linear law could only be adequate as a first approximation.   We
shall here assume that a *parabolic* approximation is adequate, if the parabola is
chosen to have the tangent at its vertex parallel to l, and seek to determine the best
available parabola by means of a further application of least-squares technique.

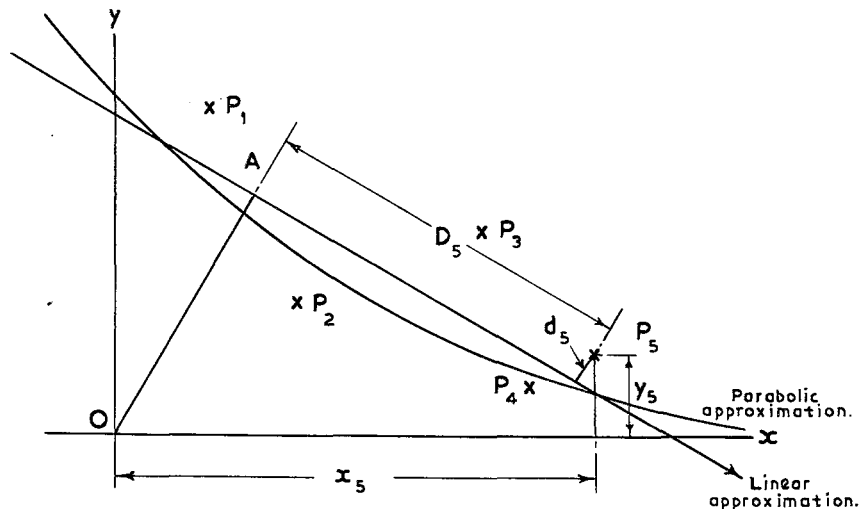2. DETERMINATION OF THE REQUIRED PARABOLA FROM OBSERVATIONS.

Fig. 9 - Linear and parabolic empirical curves

In Fig. 9 the horizontal x-co-ordinate represents distance (in km) while the vertical y-co-ordinate represents field strength in decibels above $1\mu V/m$. The points $P_r(x_r, y_r)$ for $r = 1, 2 \ldots n$ (here $n = 5$) represent observed results.

The linear approximation

$$y = mx + c \tag{1}$$

is obtained by solving the simultaneous equations

$$\left.\begin{array}{rcl} \sum\limits_{r=1}^{n} y_r & = & m \sum\limits_{r=1}^{n} x_r + nc \\[2em] \sum\limits_{r=1}^{n} x_r y_r & = & m \sum\limits_{r=1}^{n} x_r^2 + c \sum\limits_{r=1}^{n} x_r \end{array}\right\} \tag{2}$$

and the value of m will be small and negative. We now assume that the parabola required touches a line parallel to the linear approximation l at its vertex, and to obtain its equation it is convenient to change the co-ordinate system. We take as our new origin the foot A of the perpendicular from O (where x and y are both zero) to the line l, and axes along the line l in the direction of the arrow and along OA. We then have, if a particular point P has co-ordinates (x, y) under the original system and (D, d) under the new system

$$d = \frac{y-mx-c}{(1+m^2)^{\frac{1}{2}}} \qquad\qquad D = \frac{my+x}{(1+m^2)^{\frac{1}{2}}} \tag{3}$$

In Fig. 9, x, y, D and d are indicated for the point P_5 and we now seek a parabolic approximation of the form

$$d = \alpha + \beta D + \gamma D^2 \tag{4}$$

α, β, γ being determined by the simultaneous equations

$$\left.\begin{array}{rcl} \sum\limits_{r=1}^{n} d_r & = & n\alpha + \beta \sum\limits_{r=1}^{n} D_r + \gamma \sum\limits_{r=1}^{n} D_r^2 \\[2em] \sum\limits_{r=1}^{n} d_r D_r & = & \alpha \sum\limits_{r=1}^{n} D_r + \beta \sum\limits_{r=1}^{n} D_r^2 + \gamma \sum\limits_{r=1}^{n} D_r^3 \\[2em] \sum\limits_{r=1}^{n} d_r D_r^2 & = & \alpha \sum\limits_{r=1}^{n} D_r^2 + \beta \sum\limits_{r=1}^{n} D_r^3 + \gamma \sum\limits_{r=1}^{n} D_r^4 \end{array}\right\} \tag{5}$$

and d_r, D_r being obtained from (3) with x replaced by x_r and y by y_r.

For numerical work it is convenient to replace D_r by

$$D_r - \frac{1}{n} \sum\limits_{r=1}^{n} D_r$$

in (5) because smaller numbers then arise in (5). This is merely equivalent to shifting the origin of the (D, d) co-ordinate system along the line l.

Goodness of fit is measured for the linear approximation by

$$A = \frac{1}{n} \sum_{r=1}^{n} P_r Q_r^2$$

and for the parabolic by

$$B = \frac{1}{n} \sum_{r=1}^{n} P_r R_r^2$$

Q_r being the point on the line l vertically above or below P_r and R_r being the point on the parabola vertically above or below P_r. Now

$$A = \sum_{r=1}^{n} (y_r - mx_r - c)^2 = (1 + m^2) \sum_{r=1}^{n} d_r^2 \tag{6}$$

In the general case there is no simple expression for B. Knowing x_r, we have to substitute from (3) into (4) and put x_r for x to obtain a quadratic for the corresponding value y_r' of y at R_r on the parabola, but if m and d are regarded as small, we have that when $x = x_r$, $D = D_r'$ where

$$D_r' = \frac{my_r' + x_r}{(1 + m^2)^{\frac{1}{2}}} \simeq \frac{m(mx_r + c) + x_r}{(1 + m^2)^{\frac{1}{2}}}$$

$$= x_r(1 + m^2)^{\frac{1}{2}} + mc(1 + m^2)^{\frac{1}{2}} \simeq x_r + mc \tag{7}$$

Substitution in (3) then gives the corresponding value d_r' of d, and y_r' is then given by

$$y_r' = mx_r + c + d_r'(1 + m^2)^{\frac{1}{2}} \simeq mx_r + c + d_r' \tag{8}$$

so that, when m, d are small

$$B \simeq \sum_{r=1}^{n} (y_r - mx_r - c - d_r')^2 \tag{9}$$

B is always less than or equal to A; if B is between, say, $0{\cdot}9A$ and A, it would hardly be worth replacing the linear approximation by the parabolic, but if B is less than, say, $0{\cdot}9A$, the superiority of the parabolic approximation is appreciable. In a practical case of five field-strength/distance observations to which this technique was applied, B was found to be about $\frac{1}{2}A$.